The FY1999 Office of Naval Research SECNAV/CNO Chair
and
ONR/MIT Scholar of Oceanographic Sciences

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LONG-TERM GOALS

Our long term goals are to:

(1) to develop physics based algorithms which improve the performance of US Navy sonar systems.

(2) to promote the coupling between the basic and applied (6.1 and 6.2) and to operational systems used for USN sonar systems.

OBJECTIVES

The technical objective of the proposal is to optimize the performance of both sonar and ocean remote sensing systems by coupling physical and statistical environmental models to state of the art, physics based, signal and array processing methods. This objective has long been sought; however, it has been quite difficult to attain. At one extreme, acoustical oceanographers conduct detailed geoacoustic observations and process studies with little concern upon their impact, while at the other extreme, sonar signal processors typically use the simplest environmental models which ignore much of what is known about the acoustic medium in which the signal and noise fields propagate.

APPROACH

Our primary approach has been to conduct basic research in ocean acoustics that combines statistical signal processing, wave propagation and scattering. To assist us in this purpose and to support the next generation of researchers in acoustical oceanography, we have opened and filled a position for a new Postdoctoral Fellow. The Fellow was chosen after a national search was advertised under the auspices of the SECNAV/CNO Chair/Scholar Award. Five candidates were interviewed from a pool of twenty qualified applicants. Dr. Aaron Thode from the Marine Physical Laboratory of Scripps Institution of Oceanography was selected to fill the position. Because of the long lead time associated with the search process required by MIT in filling post position, we plan to advertise a second position authorized in the award this spring.

WORK COMPLETED AND RESULTS

The following is a list of Navy interactions enabled by SECNAV/CNO Chair:

1) Acoustical Observatory: The SECNAV/CNO Chair has led a panel of national experts on oceanography, acoustics and sonar signal processing for the development of an "acoustic observatory." The overall objective of the observatory is to understand all issues required for the USN to maintain acoustic superiority with its systems. This panel was the direct result of a JASON summer study in 1997 and the Naval Studies Board Report, "Technology ..... for Navy 21." The initial findings were briefed to ONR Code 32, TTO DARPA and OPNAV N87 on December 22, 1998. The technical content was uniformly praised for its focus on the issues limiting the performance of USN sonars. The same groups met in April where the decision to concentrate on littoral systems was made. The "acoustic observatory" panel reconvened December 2-3, 1999 with the objective of defining a littoral observatory system by late spring 2000. The briefing on the objectives of the "acoustic observatory" was given at the Naval Symposium on Underwater Acoustics meeting in February 1999.

2) Tactical Oceanography: The SECNAV/CNO Chair attended the Tactical Oceanography symposium in February 1999 at Corpus Christi NAS. The theme of the symposium concentrated on mine counter measures (MCM). The objective of the Chair was to couple the needs of the sonar signal processing used for MCM and the limits of environmental data.

3) METOC meeting: The SECNAV/CNO Chair attended the METOC meeting in October 1999.

4) Oceanographer of the Navy: The SECNAV/CNO Chair met with the Oceanographers of the Navy, ADM Ellis and ADM West several times throughout the year. Topic discussed included: i) education programs for Naval officers (the Chair is a former Director of the MIT-WHOI Joint Program); ii) the "acoustic observatory," and a review of the MIT-WHOI Joint Program for USN officers.

5) ONR Geoacoustic Clutter program: Both the SECNAV/CNO Chair and Scholar led the ONR program initiative for geoacoustic clutter.

6) Submarine Superiority Technical Advisory Group: The SECNAV/CNO Chair is a member of this panel for N87. It provided advise to N87 on the APB (Advanced Processor Build) / ARCI Acoustic Rapid COTS Insertion) for submarine sonars. The SECNAV/CNO Chair was a member of the original CNO Sonar Panel which recommened the APB/ARCI process to improve the performance of submarine sonars.

7) NRC Undersea Weapons: The SECNAV/CNO Chair is a member of the Naval Studies Board panel reviewing Undersea Weapons. The findings of the panel will soon be submitted for National Academy review.

8) Sonar Systems and Oceanography Training: The SECNAV/CNO Chair is working with SUBLANT and SUBDEVRON-12 to develop a short course for CO's and XO's on how the oceanographic environment influences the performance of the sonar systems, especially the APB/ARCI systems.

9) Special panels: The SECNAV/CNO Chair interacts with several USN panels whose objectives are classified.

Activities of the Scholar:

Professor Makris has used SECNAV funds to help initiate new ONR Programs on Acoustic Reverberation in Shallow Water. These programs include

(1) the AsiaEx initiative, a major international set of experiments in Asia,

(2) the new ONR Geoclutter Program, for which Prof. Makris is now the joint Chief Scientist in Acoustics.

The Geoclutter Program is multi-disciplinary and multi-institutional and exits under the sponsorship of Dr. Joe Kravitz and Dr. Jeff Simmen. It has both an experimental and theoretical component and involves major at-sea experiments in both acoustics and geophysics.

Prof. Makris is currently supervising the new Post Doctoral Fellow, Dr. Aaron Thode, as well as two new graduate students under SEC/NAV funds. These new personnel are currently working on problems in ocean-acoustic remote sensing.

The following is a summary of research conducted by the Scholar this year:

(A) Statistical Ocean Acoustics

 In recent years, a wide variety of acoustic techniques have been developed to probe the marine environment. These techniques typically require the nonlinear inversion of acoustic field data measured on a hydrophone array. The data, however, are often randomized by the addition of naturally occurring ambient noise or by fluctuations in the waveguide's refractive index and boundaries. The nonlinear inversion of random data often leads to estimates with biases and

variances that are difficult to quantify analytically. It has become popular in recent years to (1) simply assume that biases are negligible and to (2) compute limiting bounds on the variance of these nonlinear estimators, since these bounds are usually much easier to obtain than the actual variance. A major problem, however, is that the estimators may be strongly biased and that the bounds are only guaranteed to converge to the true variance of the estimator under sufficiently high signal-to-noise ratio (SNR).

One of the primary objectives of this year's research has been to apply higher order asymptotic theory to derive general expressions for the 1st-order-bias and 2nd-order-variance of a general maximum likelihood estimate and to apply these expressions in a variety of ocean acoustic inverse problems, such as matched field processing, matched field inversion and active sonar range estimate. The specific objectives have been to (1) demonstrate that the bias in these problems can be extremely large and that the Cramer-Rao lower bound provides an unrealistically optimistic estimate of the true variance and (2) to determine requisite conditions on sample size and signal to noise ratio for the bias to become negligible and the estimators to attain minimum variance.

In particular, Prof. Makris and his students have shown that when matched field processing is used to estimate the range and depth of a source in an ocean waveguide significant biases in depth estimation can occur and that the Cramer-Rao bound provides an unrealistically optimistic estimate of the true range and depth variances unless the signal to noise ratio is very high.

Professor Makris and his students have also applied our asymptotic expressions to determine analytic conditions in which the matched filter attains the Cramer-Rao bound in sonar range estimation and Doppler shift estimation problems. They find that the SNR must typically be in excess of 20 dB before the variance of the range or Doppler shift estimate can attain the Cramer-Rao bound. They also find that while the first order range resolution increases with increasing signal bandwidth so does the second order variance in relation to the first order variance.

(B) A Unified Model For Reverberation and Submerged Target Scattering in a Stratified Ocean Waveguide

Professor Makris and his students have developed the first unified full-field model for reverberation and submerged object scattering in a stratified ocean waveguide. The model handles target, volume and interface scattering with a full field analytic formulation. It has enabled numerous predictions to be made to determine when returns from a submerged target will or will not stand above returns from the seafloor. In a typical shallow-water active sonar scenario, conditions necessary for successful detection are found to be highly dependent upon the environmental parameters of the waveguide, the source and receiver configuration and geometry as well as the signal structure.

This research has been conducted to support a proposal for the major new ONR Geoclutter Program that has recently been accepted.

Invited talks of the Chair:

1) George Mason University Distinguished Lecturer, December 18, 1999, "Acoustic Thermometry of Arctic Ocean Climate"

2) NATO SACLANT Ctr, January 26, 1999, "The State of the Art of Acoustic Telemetry"

3) ONR-Scientifique National de France Symposium on Acoustic Imaging, Cargese, France, May 3, 1999. "Sonar Imaging Systems"

4) New England Aquarium, Lowell Distinguished Lecturer, May 13, 1999, "The Future of Acoustics in Ocean Exploration"

5) Fall 1999 Acoustical Society Meeting, Robert J. Urick Memorial Session, "Transducer Arrays: The Directivity Index (DI)"

Invited talks of the Scholar:

(1) December 1998, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," Distant Thunder Review, CLASSIFIED, Office of Naval Research, Washington, DC.

(2) December 1998, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," Naval Research Laboratory, Washington, DC.

(3) March 1999, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," BBN, New London, CT.

(4) April 1999, "A foundation for logarithmic measures of fluctuating intensity in pattern recognition," Distinguished Lecture Series in Applied Mathematics, RPI, Troy, NY.

(5) May 1999, "Asymptotic Inference in Ocean-Acoustic Inverse Problems," Workshop on Inverse Problems in Underwater Acoustics, Institution of Applied and Computational Mathematics, Heraklion, Crete.

(6) June 1999, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," ONR Planning Meeting on Geological Clutter, Washington, DC.

(7) July 1999, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," ONR Third International Meeting on Shallow Water Acoustics, Girwood, Alaska.

(8) August 1999, "Scattering from a fluctuating target submerged in a fluctuating waveguide," ONR Signal Processing Peer Review, CLASSIFIED, SPAWAR, San Diego, CA.

(9) August 1999, "A unified seafloor reverberation and submerged object scattering model for shallow water detection, localization and imaging," Workshop on Seafloor Reverberation, Santa Fe, New Mexico.

(10) October 1999, "Geological Clutter," LWAD Planning Meeting, CLASSIFIED, Washington, DC.

Contributed talks of the Chair

1) "Propagation modeling of T Phases with RDOASES," Sperry, B., Schmidt, H. and Baggeroer, A.B., 1999 Spring Meeting of the Acoustical Society of America

2) "Broadband receptions at megameter ranges," Wage, K. and Baggeroer, A.B., 1999 Spring Meeting of the Acoustical Society of America

3) "Stochastic matched field processing," Baggeroer, A.B. and Scheer, E.K., 1999 Fall Meeting of the Acoustical Society of America

4) "Limits on Nulling Multiple Moving Ships Using Large Aperture Towed Arrays," Baggeroer, A.B. and Cox, H., 1999 Asilomar Conference on Signals and Systems

PUBLICATIONS

(1)   N.C. Makris, C.S. Chia, L.T. Fialkowski, "The bi-azimuthal scattering distribution of an abyssal hill," J. Acoust. Soc. Am. , 1999.

(2)   C. S. Chia, N. C. Makris, L. T. Fialkowski, "A comparison of bistatic scattering from two geologically distinct abyssal hills," J. Acoust. Soc. Am. (submitted)

(3)   D. Kilfoyle, A.B. Baggeroer, "The-state- of- the- art of acoustic telemetry" to appear Journal of Oceanic Engineering, Jan.2000.